A Fifty-Year Analysis of Global Ocean Surface Heat Flux to Improve the Understanding of the Role of the Ocean in Climate

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Project summary

The ocean and the atmosphere exchange heat at their interface via a number of processes: solar radiation, longwave radiation, sensible heat transfer by conduction and convection, and latent heat transfer by evaporation of sea surface water. The amount of heat being exchanged is called heat flux. The distribution of heat flux over the global oceans is a key element for climate studies, as it is required to establish air-sea feedback mechanisms, to provide guidance and motivation for modeling studies, to verify individual or coupled atmosphere-ocean general circulation model simulations, and to serve as forcing functions for ocean model exercises. However, direct flux measurements are sparse. Our present knowledge of the global air-sea heat flux distribution stems primarily from the bulk parameterizations of air-sea fluxes as functions of surface meteorological variables (e.g., wind speed, temperature, humidity, cloud cover, etc). The source of observations for those flux-related variables includes marine surface weather reports from Voluntary Observing Ships (VOS) collected by Comprehensive Ocean-Atmosphere Data Set (COADS) and satellite remote sensing from various platforms. Atmospheric reanalyses from numerical weather prediction (NWP) centers such as National Centers for Environmental Prediction (NCEP) and the European Centre for Medium-Range Weather Forecasts (ECMWF) provide additional model-based database. Nonetheless, none of the three data sources are perfect as each suffers from at least one of the four deficiencies: (1) incomplete global coverage, (2) relatively short time series, (3) systematic bias, and (4) random error.

While improving the quality of each data source is a necessary step toward improving the estimates of surface heat fluxes, this project takes an alternative approach, i.e., to improve the quality of the flux estimates through objectively synthesizing the advantages of the three data sources. The synthesis approach has been applied successfully to generate gridded products of surface vector wind, SST, and precipitation. This project, which is termed "Objectively Analyzed air-sea heat Fluxes (OAFlux)", develops an equivalent global synthesis product for surface heat fluxes by utilizing the methodology developed and experience learnt from a previous pilot study for the Atlantic Ocean.

The project has two main objectives. The first objective is to produce a 50-year (from the mid 1950s onward) analysis of surface latent, sensible, net shortwave and net longwave radiation fluxes over the global oceans with improved accuracy. This is to be achieved by an appropriate combination of COADS data, NWP reanalysis outputs, and satellite retrievals using advanced objective analysis. The target resolution is 1° longitude by 1° latitude and monthly. Daily flux fields are produced when satellite data are available. The second objective is to use the data to study the heat flux variability on seasonal, annual, interannual, decadal and longer timescales and their relation to global climate change. The scientific investigation helps to assess the quality and reliability of the dataset in depicting the multi-decade climate record since 1950s and to provide physical insights into the dataset.

A nearly 50-year (1958-present) analysis of global surface latent and sensible heat fluxes with monthly and daily resolutions has been completed. The datasets are to be released by the end of 2007 and are freely available to the community via the project website (http://oaflux.whoi.edu). The proposed study contributes to CLIVAR programs including CLIVAR Atlantic, Pacific and PACS, and benefits the CLIVAR and other research communities on studies of climate variability and predictability.

Accomplishments

(i) Datasets of air-sea latent and sensible heat fluxes (1958-2006)

We have completed the global analysis of air-sea latent and sensible heat fluxes along with error field estimates for the years from 1958 to 2006 (Fig.1).

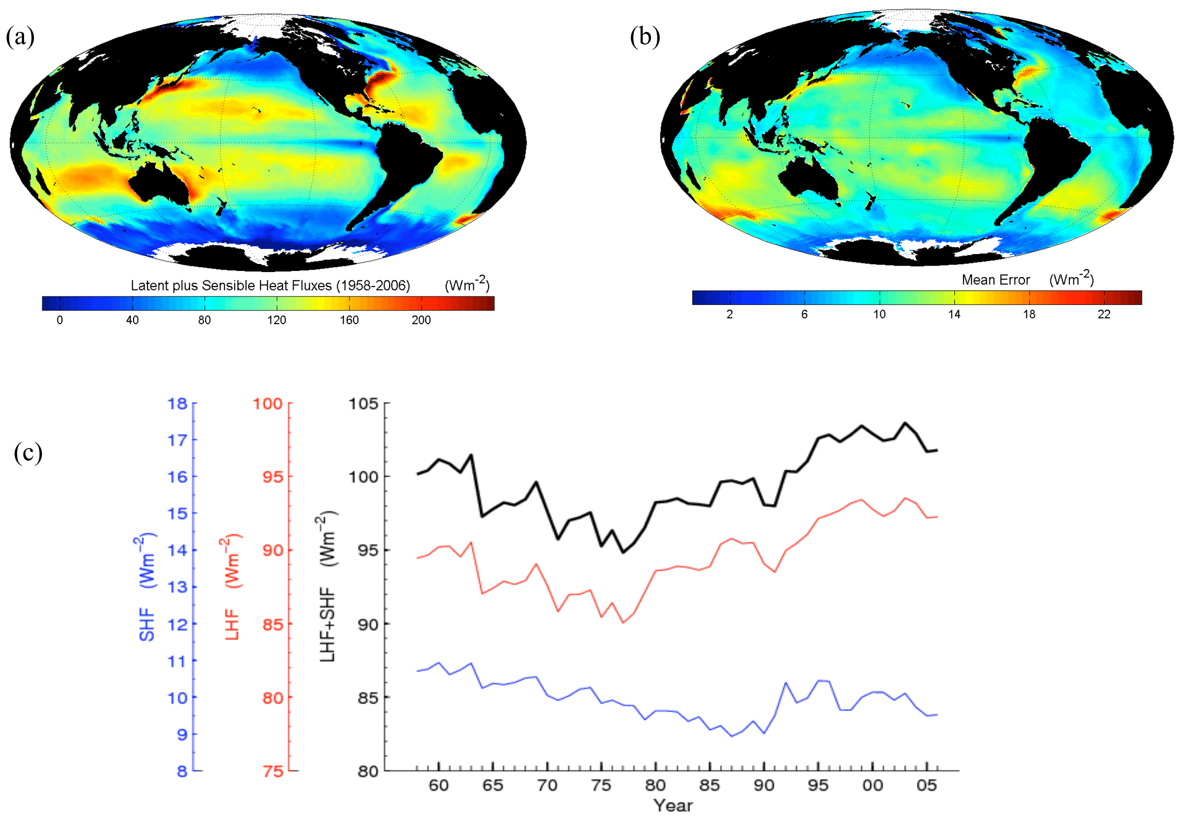


Fig.1 (a) Annual mean latent plus sensible heat fluxes averaged over the 49 year period (1958-2006). (b) Mean error (standard deviation) of the latent plus sensible heat fluxes. (c) Time series of annual-mean latent (red), sensible (blue), and latent plus sensible heat fluxes averaged over global oceans.

The 49-year global daily flux analysis is developed from synthesizing 22 sets of daily variable fields. The 22 input data sets originate from three NWP reanalyses (ERA40, MCEP1, NCEP2) and multiple satellite platforms (AVHRR, SSM/I, QuikSCAT, AMSR-E). The methodology, strategy, and procedure used in developing the 49-year time series were detailed in a technical report (Yu et al. 2007). Also discussed in the report is the accuracy of the OAFlux products. We have conducted long-term mean comparison using COADS-based (1950-2005) climatological flux atlases, and validated the OAFlux daily time series with in situ daily flux measurements at 107 locations (105 buoys plus 2 ships). The OAFlux estimates have good agreement with long-term means of COADS-based climatologies. Daily latent plus sensible heat flux estimates are unbiased and have the smallest mean error: the mean OAFlux-buoy difference is of 1.0 Wm^{-2} and the mean OAFlux-buoy difference in absolute measure is of 7.4 Wm^{-2}. By comparison, NWP reanalyzed fluxes are largely overestimated (Fig.2).

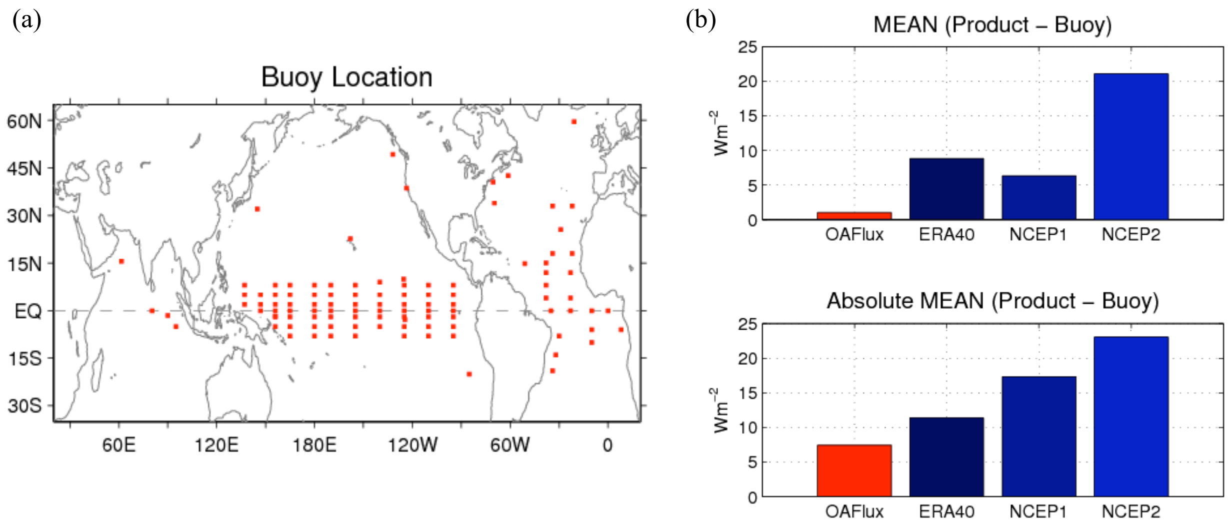


Fig.2 (a) Location of the 105 buoys used in validation analysis. (b) Differences in latent-plus-sensible heat fluxes between product (OAFlux, ERA40, NCEP1, and NCEP2) and buoy averaged over the 107 (105 buoys pus 2 ships) in situ locations. Top panel: mean average (positive and negative signs cancel each other; a measure of bias); Bottom panel: mean average in absolute measure (signs are ignored; a measure of mean variance).

The technical report will support the public release of the 49-year global flux time series at the end of 2007 (http://oaflux.whoi.edu/). This will be the third release[1] of the OAFlux data products that include global latent and sensible heat fluxes, flux-related surface meteorological fields, and error estimates for each flux and variable fields. Monthly products will be available for the entire 49-year period, and daily products will be available from 1985 to 2006, the period that satellite observations became dominant input datasets during OAFlux synthesis.

(ii) Understanding the long-term variability of global heat and water cycle

The 49-year time series (Fig. 1c) shows that the decadal change of the global latent heat flux is marked by a distinct transition from a downward trend to an upward trend around 1977-78. The upward trend coincided with the rapid rise of global sea surface temperature in the 1980s–1990s, suggesting a response of the atmosphere to oceanic forcing (Yu and Weller 2007).

The air-sea latent heat exchange releases not only heat energy but also water vapor to the atmosphere. The ocean evaporation accounts for 86% of global evaporation and is a key

[1] The first version of the OAFlux products was made for the Atlantic Ocean (1988-1999) and released in March 2004. The second version was for the global oceans (1981-2002) and released in December 2005.

component of global water cycle. An increased latent heat flux means increased ocean evaporation and is an indicative of a changing global water cycle (Yu 2007). Evidence of a changing water cycle has been shown in seawater salinity variations. The saltier northern and southern subtropics of the Atlantic Ocean from the 1950s to the 1990s implied a 5–10% increase in net evaporation (i.e., evaporation minus precipitation). Our time series from 1958 to 2006 shows that the ocean evaporation in 1990s is higher than that in early 1960s, consistent with the pattern of change projected by salinity observations.

(iii) Sea-surface shortwave and longwave radiation

Extensive efforts have been made to (1) understand the problems in existing sea-surface shortwave and longwave radiation over the global basins and to (2) develop daily surface radiation products with improved accuracy. Currently, there exist two surface radiation products computed from satellite observations and ancillary data; one is from the International Satellite Cloud Climatological Project (ISCCP) and the other from the NASA/GEWEX Surface Radiation Budget (SRB). These products are not error free. We identified three major biases in the products after comparison analysis with ship-based climatological atlases and with pyranometers (downward shortwave measurements) at 62 buoy locations (Fig.3) and pyrgeometers (downward longwave measurements) at 24 buoy locations (not shown).

(a)

(b)

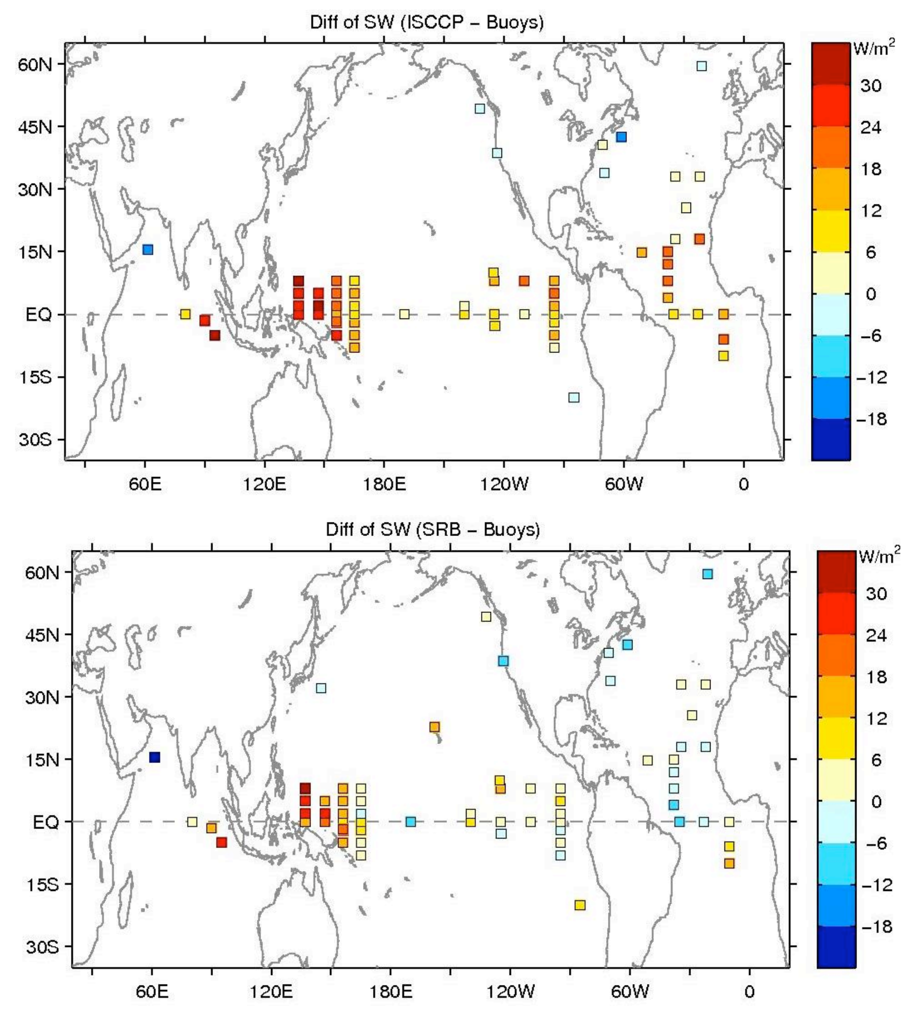


Fig.3 (a) Mean difference between ISCCP and buoy shortwave radiation. (b) Mean difference between SRB and buoy shortwave radiation.

The first problem is the large overestimation of ISCCP incoming solar radiation in the equatorial oceans. ISCCP is severely biased, with the largest bias (>30Wm^{-2}) over the western tropical Pacific and eastern Indian warm water regions. Outside of the equatorial regions, the ISCCP net shortwave radiation is slighted underestimated. By comparison, SRB does a better job in estimating solar radiation. Although there is a similar overestimation bias over the Indo-Pacific warm pool regions, the SRB-buoy differences over other buoy locations are comparatively small (±6Wm^{-2}). The second problem is the spurious reduction in the timeseries of longwave radiation averaged over the global oceans in both ISCCP and SRB datasets (Fig.4). There discontinuities are caused by spurious change of the atmospheric temperature products from the NOAA operational TOVS. The third problem is the so-called the "Indian Ocean Gap" (Fig.5), due to lack of coverage from geostationary satellites over an area centered on 70°E for all of the July 1983 - June 1998 time period, except for April 1988 – March 1989, when data from the INSAT satellite is available to cover the gap. In July of 1998, Meteosat-5 was moved over the gap area, eliminating the gap. Because of the three problems, neither ISCCP nor SRB surface radiation products are ready for climate analysis and modeling study.

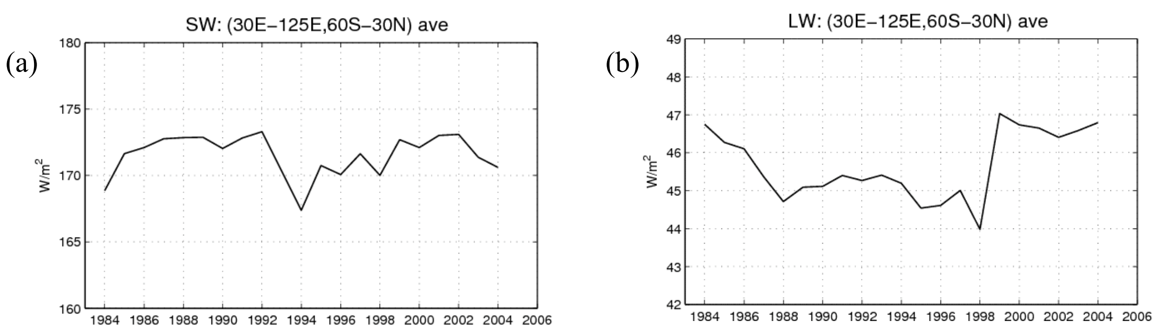


Fig.4 Time series of yearly-mean (a) shortwave (SW) and (b) longwave (LW) radiation averaged over the Indian Ocean. The sudden changes in LW in 1988 and 1999 are spurious.

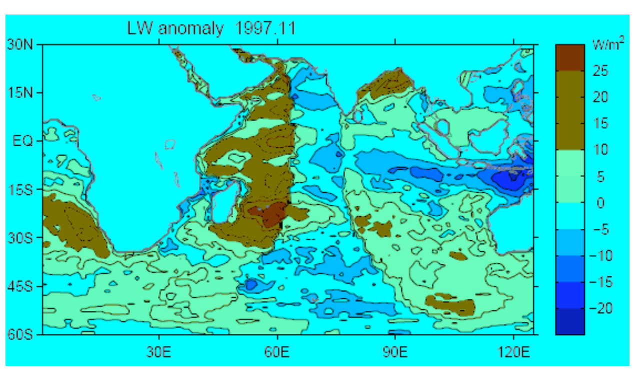


Fig.5 The spatial structure of "The Indian Ocean Gap" in the longwave radiation in November 1997.

Our analyses show that SRB is better than ISCCP in that (1) the mean shortwave radiation is close to buoy mean within ±6Wm^{-2} over most buoy locations except the Indo-Pacific warm pool regions, (2) the time series of SRB longwave radiation is less spurious, and (3) SRB shows better interannual variability (Nof and Yu 2007). But SRB is no any better than ISCCP in the Indian Ocean gap region. In developing an improved daily surface radiation product, the strategy of OAFlux is to use SRB daily estimates as the base and to implement a series of corrections to the base data. Preliminary progress has been made in correcting the Indian Ocean gap (Fig.6). The jump between the inside and outside regions of the gap is caused by two factors. One is the temporal resolution of satellite. The polar orbiting satellites used in filling the gap have only one or two daytime overpasses per day, while geostationary satellites that cover the rest areas have 3-5 times overpasses per daytime depending upon the latitude (between 55 degrees North and South) and the time or year. The other factor is the mean drift in satellite cloud observations. The gap boundaries may suffer from spuriously high cloud amounts due to large view angles. This results in an abrupt drop-off of cloud fraction in the gap as compared to the gap boundaries, and results in a flux discontinuity (Yu 2007b). All in all, the gap is caused by a drift in the mean when there is no coverage from geostationary satellites.

We implemented a smoothing approach to adjust the mean in the gap using EOF modes. The mean adjustment was based on the monthly-mean datasets. We performed EOF analysis for monthly time series for each month, and for each mode we tuned the mean in the gap to match the means of the eastern and western regions outside of the gap, and after that, we reconstructed the field using the mean-adjusted modes. The original SRB radiation fields in the Indian Ocean and the fields after adjustment are shown in Fig.5.

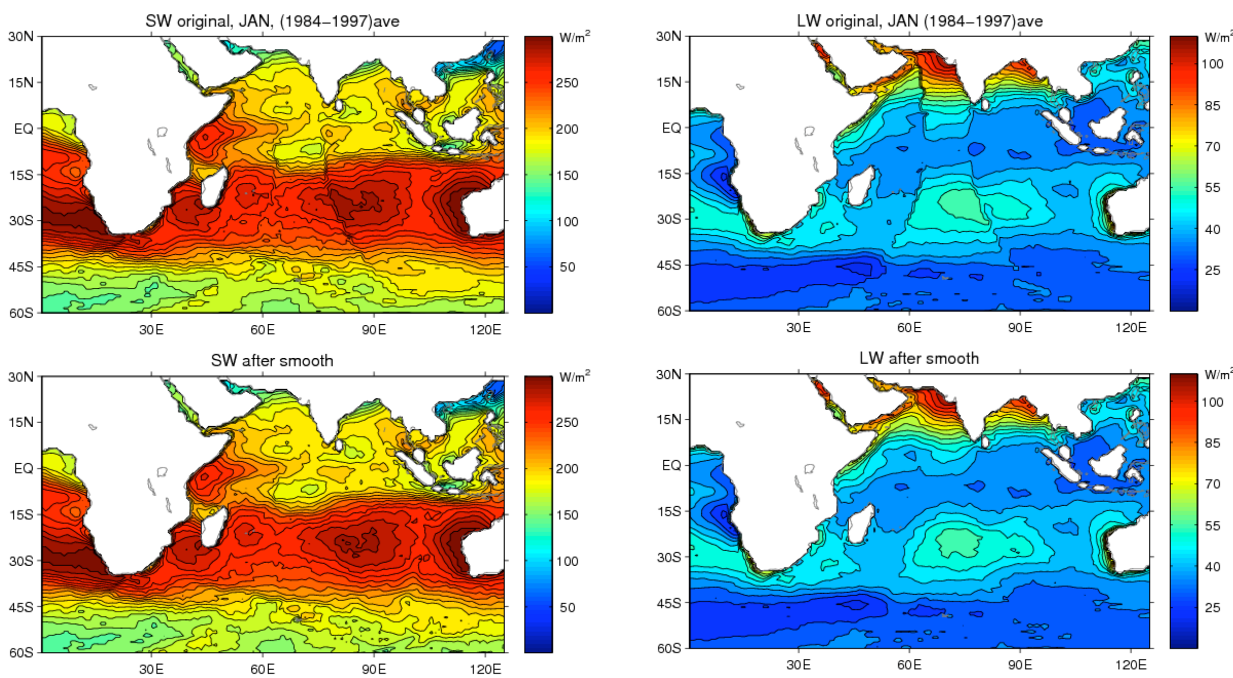
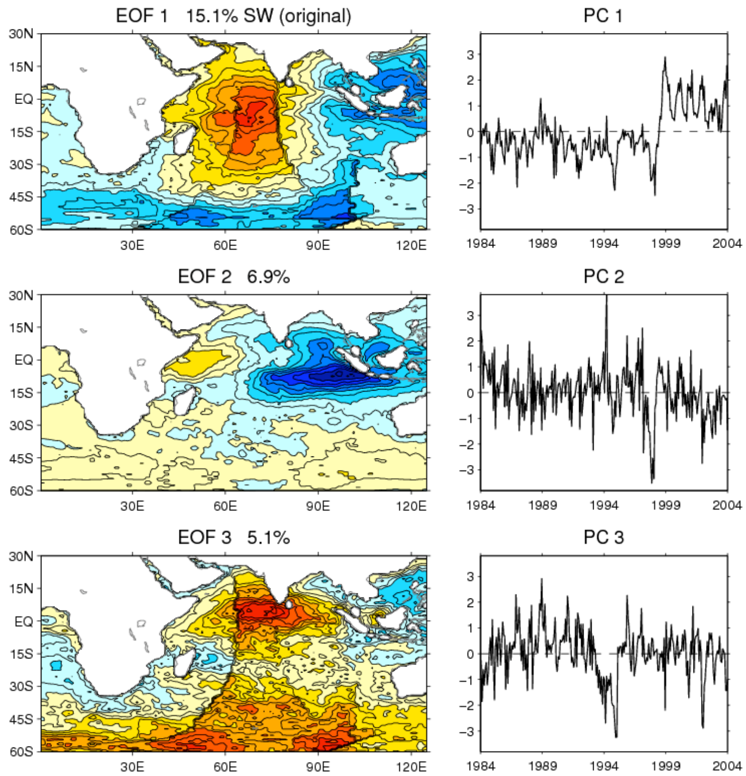


Fig.6 (a) Shortwave and (b) longwave radiation fields in the Indian Ocean from SRB (top panels) and after OAFlux correction (bottome panels).

A key question is whether the mean adjustment alters the variability of the original datasets. Fig.7 shows the first three EOF modes derived from the SRB monthly datasets and from the mean-adjusted monthly datasets. It is apparent that our approach improves the spatial pattern of the modes while retains the variance of the mode and the corresponding principle component (PC) variability.

(a)



(b)

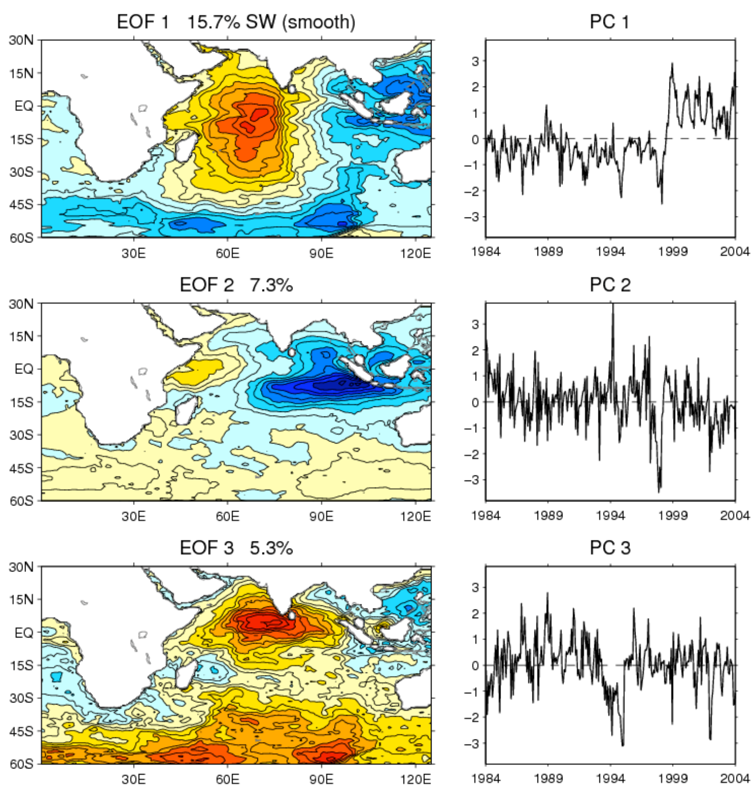


Fig.7 The first three EOF modes derived from the SRB monthly datasets and from the mean-adjusted monthly datasets for the shortwave radiation in the Indian Ocean.

In summary, we have achieved the following in the past year:

(1) Completion of a nearly 50-year global analysis of latent and sensible heat fluxes over global oceans.
(2) Completion of validation analysis using 107 in situ measurement time series.
(3) Completion of error estimation for flux analysis and flux related variables.
(4) Public release of the OAFlux datasets (global latent and sensible heat fluxes and flux-related surface meteorological variables and their error estimates) by the end of 2007.
(5) Completion of 7 refereed manuscripts and 1 WHOI technical report.
(6) Completion of validating ISCCP and SRB shortwave and longwave radiation with 64 pyranometers and 24 pyrgeometers, from which three major error types are identified and a strategy for improving radiation estimates is developed.
(7) Invention of an EOF-mode based smoother to reduce the flux discontinuity caused by the "Indian Ocean Gap".

Publications and reports

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